PROBABILITY OF OVERLOAD OCCURRENCE IN A SINGLE CELL WCDMA SYSTEM

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Abstract: A WCDMA (Wideband Code Division Multiple Access) system capacity usually is defined as maximum number of simultaneous users satisfying QoS (Quality of Service) requirements. Radio interface characteristics put a limit on number of supported users with specified QoS requirements. This paper evaluates capacity of a single cell WCDMA system in multi service environment, considering no power constraints in uplink. Furthermore it exposes the influence of number of users in the cell, traffic sources activity, traffic intensity and QoS requirements on overload probability in single cell WCDMA system.

1 INTRODUCTION

WCDMA (Wideband Code Division Multiple Access) is adopted as access technology in UMTS (Universal Mobile Telecommunication System). In WCDMA distinction between different users transmitting in a common spectrum, is performed by using a set of orthogonal spreading sequences (Holma, 2001). The interference level increases with the number of multiplexed user data steams. System capacity and interference management are basic problems in radio resource management research (Kim, 2005)(Perez-Romero, 2005). WCDMA system capacity has been analyzed by many authors (Gilhousen, 1991)(Jerez, 2002) (Schuler, 2000), considering no eventual overload occurrence. Using some of their conclusions about WCDMA system capacity limits, in this paper WCDMA system performance are evaluated in the means of overload probability. The overload in WCDMA system will occur when the interference outreaches maximum allowed value and system can't guarantee the required quality to the established transmissions. Number of camping users in the system, traffic sources activity and traffic intensity must be taken into account for performance evaluation of WCDMA systems, due to their influence on system behavior.

The rest of this paper is organized as follows. Section two presents WCDMA radio interface characteristics. Then, a single cell capacity is evaluated in outdoor and vehicular environment for multi service operation. In section four, the overload probability is evaluated by modelling a call arriving-serving process as simple Markov chain. Section five presents results from the analysis of overload probability in isolated WCDMA cell, under different conditions specified by number of camping users in the cell, traffic sources activity and traffic intensity. Last section concludes this paper.

2 RADIO INTERFACE CHARACTERISTICS

WCDMA system capacity is limited by interference at the receiver site introduced by users transmitting simultaneously in the common bandwidth.

Let us consider an isolated cell. According to the QoS requirements in uplink direction, received E_b/N_0 ration of the i^{th} user must satisfy the following inequality (Holma, 2001):

$$\frac{P_i\left(W/R_{b,i}\right)}{P_N+\left[P_R-P_i\right]}\geq\left(\frac{E_b}{N_o}\right)_i \tag{1}$$

$$P_R=\sum_{i=1}^{n}P_i \tag{2}$$

where $(E_b/N_0)_i$ is the required E_b/N_0 ratio for the i^{th} user, P_i is i^{th} user's received power at the base station, P_N is the background noise power, W is the spreading sequence chip rate, $R_{b,i}$ is the i^{th} user's bit rate and P_R is the total received power at the base station.

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$$P_i = \frac{P_N}{\left[1 + \frac{W/R_{b,i}}{\left(\frac{E_b}{N_0}\right)_i}\right]\left[1 - \sum_{j=1}^{n} \frac{1}{\frac{W/R_{b,j}}{\left(\frac{E_b}{N_0}\right)_j} + 1}\right]} \qquad (3)$$

Assuming equality conditions, combining equations (1) and (2), the received power for the i^{th} user's connection is given by equation (3).

Having in mind that received power has to be grater then 0 , $P_i > 0$, following inequality has to be satisfied:

$$\sum_{j=1}^{n} \frac{1}{\frac{W/R_{b,j}}{\left(\frac{E_b}{N_0}\right)_j} + 1} < 1 \qquad (4)$$

3 CAPACITY OF A SINGLE CELL

Let us consider *K* user classes existing in the cell, including on class of voice users and *K*-1 various classes of data services. The voice user class comprise K_v users and each of data classes contains $K_{d,j}$ users, where j = 1, 2, …, *K*-1 denotes difference between data classes. Inequality (4) can be re-written in the form:

$$\sum_{i=1}^{K_v} \frac{1}{\frac{(W/R_{b,i})}{\left(\frac{E_b}{N_o}\right)_i} + 1} + \sum_{j=1}^{K-1}\sum_{i=1}^{K_{d,j}} \frac{1}{\frac{(W/R_{b,i})}{\left(\frac{E_b}{N_o}\right)_i} + 1} < 1 \qquad (5)$$

Having in mind that all users that belong to the same service class have same QoS requirements, R_b and E_b/N_0, equation (5) can be simplified:

$$K_v \frac{1}{\frac{(W/R_{b,i})}{\left(\frac{E_b}{N_o}\right)_i} + 1} + \sum_{j=1}^{K-1} K_{d,j} \frac{1}{\frac{(W/R_{b,i})}{\left(\frac{E_b}{N_o}\right)_i} + 1} < 1 \qquad (6)$$

Equation (6) specifies a WCDMA system capacity plane in the *K* dimensional space (Kim, 2005). All points (K_v, $K_{d,1}$, $K_{d,2}$, …, $K_{d,K-1}$) under this *K* dimensional plane, represents possible combination of supported users in voice and data user groups in a cell.

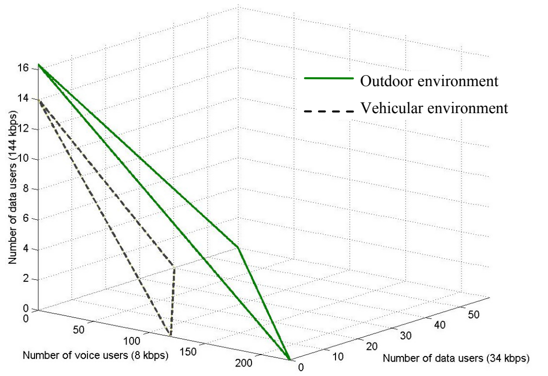

Figure 1: Three-dimensional capacity planes for the one voice and two data user clases in outoor and vehicular environment.

Table 1: QoS parameters for voice and data services (3GPP TR 101 112-UMTS 30.03).

Service parameters	QoS requirements in uplink	
Voice Bit Rate	8 kbps	
Environment	Vehicular	Outdoor
Target Eb/N0	6.1 dB	3.3 dB
Data service 1–Bit Rate	144 kbps	
Environment	Vehicular	Outdoor
Target Eb/N0	3.1 dB	2.4 dB
Data service 2–Bit Rate	34 kbps	
Environment	Vehicular	Outdoor
Target Eb/N0	4.6 dB	2.9 dB

According to equation (6) and QoS requirements for three different services in vehicular and outdoor environment (Table 1), we can plot three-dimensional capacity planes for voice and two data user classes (Fig. 1), in both vehicular and outdoor environment. All possible combination of supported users in the scenario with one voice and two data user groups, in a single WCDMA cell, are represented with points (K_v, $K_{d,1}$, $K_{d,2}$) under this three dimensional planes. The tree dimensional plane, in fig. 1, sided by solid line, represents system capacity boundary for outdoor environment. System capacity in vehicular environment is limited by plane narrowed by dashed line.

4 NUMBER OF CAMPING, ACTIVE AND SIMULTANEOUS USERS IN THE CELL

Overload occurs when the number of simultaneously transmitting users becomes grater then maximum allowed number of transmitting voice and data users, determined by equation (4).

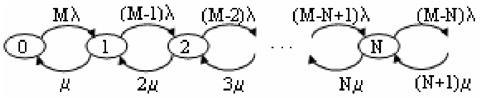

Figure 2: Markov chain describing call arriving-serving process.

Let us consider that M users are uniformly distributed in a cell. Call or session arrival process is distributed by Poisson low with average rate of λ calls/s per user, while call duration is exponentially distributed with average value of 1/μ s.

A call arrival-call ending process can be described with birth-death Markov chain (Kleinrock, 1975), where the states are given by number of active users (the users having a call in progress) (Fig. 2).

Birth and death coefficients, λ_N and μ_N, associated with state N are given by:

$$\lambda_N = (M - N)\lambda \tag{7}$$

$$\mu_N = N \cdot \mu \tag{8}$$

Under conditions of equilibrium, the probability of having N active users with call in progress is:

$$p_N = \frac{\binom{M}{N}\left(\frac{\lambda}{\mu}\right)^N}{\left(1+\frac{\lambda}{\mu}\right)^M} = \binom{M}{N}\frac{\rho^N}{(1+\rho)^M} \tag{9}$$

where ρ = λ/μ.

Traffic source behavior is usually characterized by activity factor - α, representing the fraction of time when the source is generating traffic. The probability of having n users simultaneously occupying radio interface, when N users are in call is given by:

$$p_{n/N} = \binom{N}{n}\alpha^n(1-\alpha)^{N-n} \tag{10}$$

Therefore, the probability of n simultaneously transmitting users, having M camping users in the cell, can be computed as:

$$p_n = \sum_{N=n}^{M} p_{n/N}p_N = \binom{M}{n}\frac{(\alpha\rho)^n(1+(1-\alpha)\rho)^{M-n}}{(1+\rho)^M} \tag{11}$$

5 OVERLOAD PROBABILITY

Considering capacity constrains, overload probability can be calculated as probability that number of users transmitting simultaneously is higher then maximum number of supported users calculated by equation (4), i.e.:

$$P_C = \sum_{n=K_{\max}+1}^{M} p_n \tag{12}$$

where p_n is a probability of heaving n simultaneous users in the cell, given by equation (11), K_{max} is maximum number of supported voice and data users calculated by (4) and P_C is overload probability.

The probability of overload occurrence is examined considering voice and class 1 data users, in outdoor environment, under various scenario conditions defined by: number of camping users in the cell, traffic intensity and user activity factor. Figure 3 illustrates dependence of the overload probability on number of class 1 data users camping in the cell and various values for activity factor-α while traffic intensity ρ=0.5. Dependence of overload probability on number of data class 1 camping users and various values for traffic intensity factor while α = 0.5 is presented in figure 4. Overload probability dependence on traffic intensity and activity factor for M=55 data type 1 camping users in the cell is represented in figure 5. The number of camping users in particular cell depends on cell dimensions and user density in the cell. It is obvious that, proper cell dimensioning is required in order to satisfy and guaranty recommended call blocking/dropping, established by the network planner. On the other, system capacity and overload probability depends on mixture of various services offered to and utilised by the users. Considering 300 users in the cell, figure 6 shows a dependence of overload probability on percentage of users belonging to voice users group, while rest of the users belong to data class 1. Traffic intensity ρ=0.5 and activity factor α=0.5 are considered for both voice and 144 kbps data group in outdoor and vehicular environments. It is obvious that probability of overload occurrence arises in both environments by increasing the percentage of users belonging to 144 bit/s data class, while keeping the percentage of data users at the low level overload probability is negligible.

6 CONCLUSIONS

In this paper first of all the capacity bound for uplink of a single WCDMA cell has been derived for single and multi service cases. When there is no transmission power constrains engaged, the system capacity is limited by the interference level. Also, the capacity is strongly dependent on the mixture of various services and their requirements.

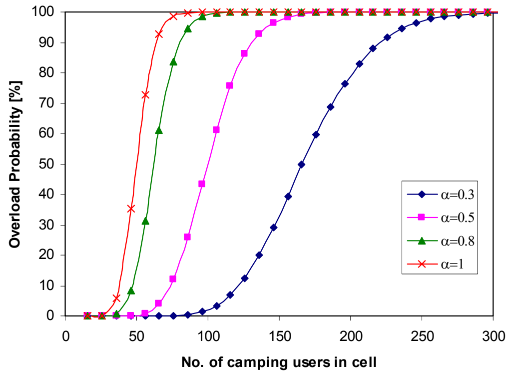

Figure 3: Overload probability dependence on number of camping users in the cell and activity factor for traffic intensity $\rho = 0.5$.

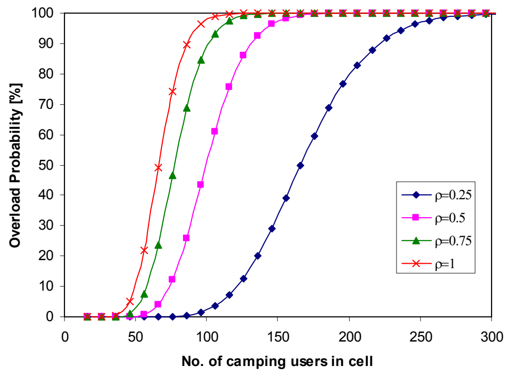

Figure 4: Overload probability dependence on number of camping users in the cell and traffic intensity for activity factor $\alpha = 0.5$.

In the process of WCDMA radio network planning, overload probability, defined as the condition that number of active users in a cell is higher then maximum number of users supported by the radio interface, has to be taken into account.

It is shown that overload probability strongly depends on number of camping users in the cell. On the other hand, number of camping users depends on cell size.

As an overall conclusion, the WCDMA cell size or cell radius has to be selected according to the planned call/session blocking and dropping probability and particular services offered in that cell.

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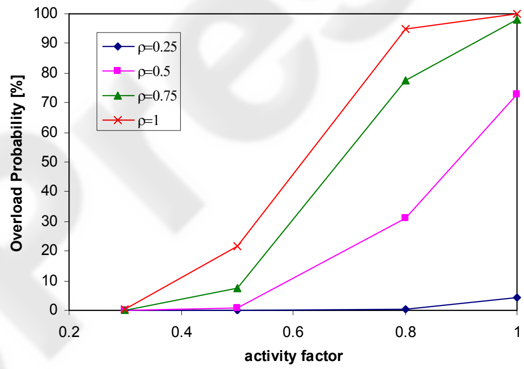

Figure 5: Overload probability dependence on traffic intensity and activity factor for M=55 camping users in the cell.

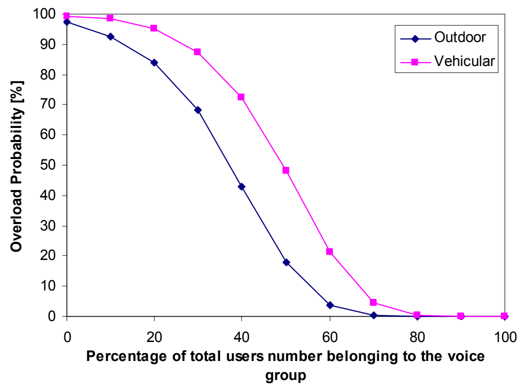

Figure 6: Overload probability in outdoor and vehicular environment depending on percentage of users belonging to voice/data group.